cc lib.

4095

R06 1060

November 1983

A SURVEY PROCEDURE TO INVENTORY PONDEROSA AND LODGEPOLE PINE MORTALITY CAUSED BY THE MOUNTAIN PINE BEETLE

by
William B. White,[1] Wayne E. Bousfield,[2] and Robert W. Young[3]

INTRODUCTION

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is a major pest of lodgepole and ponderosa pines in the western United States and Canada. The beetle's attack begins when the female constructs a vertical gallery in the cambium layer and deposits eggs. The eggs hatch, and the small larvae feed outward in routes perpendicular to the egg gallery. The feeding larvae, in combination with blue stain fungi, girdle and kill the tree.

Under endemic conditions, the beetle confines its attack to a few scattered trees weakened by overstocking, overmaturity, or root disease. Outbreak conditions occur as groups of dead trees coalesce, forming continuous areas of dead or dying trees. Infested trees display bright red foliage by July of the year following the attack. These discolored trees are commonly referred to as "faders."

Pest management specialists and forest managers use fading and group kill characteristics to identify mountain pine beetle outbreaks. Aerial sketch map surveys are conducted annually to detect and monitor outbreaks. These surveys provided information on infested areas but do not estimate numbers of trees infested nor volume loss with any degree of statistical confidence (Klein and others 1983).

This publication outlines a survey procedure for estimating tree mortality and related volume loss caused by mountain pine beetle in ponderosa or lodgepole pine over a large area, e.g., a State, Region or Forest, with a prescribed level of statistical precision. Estimates may be made for one or several intensity classes. The survey is a multi-stage, single-phase design based on a combination of stratification and multi-phase variable probability sampling (fig. 1). This sampling method has proven to be efficient in estimating mortality (Langley 1968, Hostetler and Young 1979, Bennett and Bousfield 1979).

Tree mortality is sampled by randomly selecting aerial photo plots for each outbreak area. A photointerpretation sampling grid, subdivided into subplots, is the primary sampling unit (PSU) used for each photo plot. Subplots of 2½ acres are the secondary sampling unit (SSU). Primary and secondary sampling units are selected following the probability proportional to size (PPS) technique with replacement (Cochran 1977).

[1]Entomologist, Forest Pest Management, Methods Application Group, USDA Forest Service, Fort Collins, CO 80526.

[2]Entomologist, Forest Pest Management, Northern Region, USDA Forest Service, Missoula, MT 59807.

[3]Formerly Biometrician, Forest Pest Management, Methods Application Group, USDA Forest Service, Davis, CA 95616. Present position, Analyst, Electronic Data Systems Corporation, Sacramento, CA 95825.

SURVEY PLANNING

The following time frame schedules events critical to the successful completion of a statewide survey. Each event required for the survey is described in detail in the "Methods" section of this publication.

TIME	*ACTION*
Jan.-Feb.	Decide if a survey is justified.
Jan.-Feb.	Secure funding and designate key personnel.
Feb.-Mar.	Obtain navigational aids: 1:80,000 scale, black and white aerial photos or orthophotos, and USGS 7½ minute quadrangle topographic maps for the suspected outbreak area.
March	Submit contract specifications for aerial photo flight and/or contract work. (Make sure you have an understanding with the contract officer that contracts must be awarded no later than June 15.) If contract work is not possible, obtain commitment for appropriate in-house operations. Make plans for alternative photo acquisition.
May	Acquire all necessary equipment, grids, forms, and supplies.
June	Mark recently attacked trees for periodic field checking.
	Survey
Early July	Conduct aerial sketch mapping survey.
Late July	Measure the infested area from sketch maps.
Late July	Allocate primary photo plot centers. Plot photo centers on 1:80,000 scale photography and USGS 7½ minute quadrangle maps. Deliver navigational photos and 7½ minute quadrangles to aerial photographer.
	Photointerpretation
Early Aug.	Conduct aerial photo mission.
Mid Aug. to Mid Sept.	Interpret aerial photographs. Select secondary sampling units according to probability proportional to size (PPS) procedures.
Late Sept.	Acquire ground data for selected subplots.
Oct.	Complete data analysis and issue report.

METHODS

Aerial Sketch Mapping — The survey area must first be stratified into outbreak and non-outbreak status by aerial sketch mapping. Sketch mapping should be carried out by trained aerial observers having an unobstructed view of the ground from fixed-high-wing aircraft. The aerial observer should systematically sketch the infestation on maps scaled at one-half inch to the mile and should delineate mountain pine beetle outbreaks as polygons where faders occur at a frequency of more than one per ten acres (Ciesla and Yasinski 1978). Only current faders should be delineated.

Although most regions conduct aerial sketch mapping for detection and monitoring of pests, schedules may require modification to meet the time requirements of this survey. Knowing location of host type and the outbreak boundaries of the previous year will expedite aerial sketch mapping.

Measuring the Infested Area — After sketch mapping has been completed, the acreage of each polygon must be determined. An electronic planimeter easily converts mapped areas to acres. Other less accurate methods can be used if a planimeter is unavailable, e.g., the dot grid method. Record survey information using the polygon listing sheet (app. I, form 1).

Photo Plot Allocation — For a statewide survey, 100 to 250 sample photo plots should be used to adequately measure the variation between all possible photo plots representing the outbreak area. The project coordinator must make the

decision regarding the desired number of plots based upon available resources. A 90-acre plot subdivided into 36 2½-acre subplots is most suitable for surveying ponderosa pine, and a 40-acre plot subdivided into 16 2½-acre subplots works best for lodgepole pine (Hostetler and Young 1979, Bennett and Bousfield 1979). The larger sample plot is needed for ponderosa pine because mortality tends to be more clustered. Subplots of 2½-acres are the optimum size for 100% cruise of ground plots. This area is small enough to accurately count all dead trees in a severe infestation, yet large enough to sample isolated trees.

Photo plots should be (randomly) distributed throughout all outbreak polygons by establishing a grid interval for locating photo plot centers. The grid interval can be determined with the following equation (U.S. Dept. Agric. 1970):

$$I = \sqrt{\frac{\text{Acres of outbreak}/640 \times S}{\text{Number of photo plots}}}$$

where:

I = Interval for photo allocation grid in inches.
S = Scale (inches/mile) of the map whereon photo plot centers will be designated.

A clear grid should be prepared to overlay the map of outbreak polygons after the grid interval (I) has been calculated. All grid points that fall completely inside a polygon should be transferred to the photo plot map to establish photo plot centers for aerial photography. A computer program, written in BASIC, has been developed for a Texas Instrument 990 or similar desk top graphics computer to generate the photo allocation grid. (app. II).

After all photo plot centers have been established, the number of resulting photo plots should be compared to the number chosen by the project coordinator. Fewer than the specified number of plots may result because a few centers may be rejected for falling on the edge of a polygon. A small discrepancy ($\leq$10%) will usually not compromise the results. A large discrepancy between the planned and actual number of photo plots requires a repositioning of the grid over the outbreak polygons.

Navigational aids need to be prepared for the aerial photo team. Maps at a scale of one-half inch to the mile and 1:80,000 black and white photographs or 7½ minute orthophoto quadrangles, showing plot locations and respective elevations, are sufficient.

Aerial Photo Mission — Photo missions should begin after a majority of the attacked trees have faded. Generally, new faders are at peak discoloration between August 1 and August 15. A few recently attacked trees should have been marked in early June for periodic field checking to monitor fading. (This technique offers a secondary benefit: these same trees can be used in training field crews to distinguish new faders from the previous year's mortality.)

A stereo triplet with at least 60% forward overlap for adequate stereo coverage must be taken at each plot location. A photo scale of 1:6,000 is most suitable for counting fading trees (Wear and others 1966, Hostetler and Young 1979, Bennett and Bousfield 1979, Klein and others 1979). An experienced aerial photographer should be able to locate photo plot centers within one-eighth of a mile using 1:80,000 scale, black and white navigational photos or orthophoto quadrangles. If greater precision is required, provide 1:60,000 scale photographs showing plot centers and elevations.

Aerial mapping cameras with a 9- by 9-inch film format should be used for photo acquisition. The large format provides sufficient coverage to contain adequate landmarks for field crews to locate ground plots and allows the 90-acre grid to fit into the effective photo area. The camera lens should have an 8¼- or 12-inch focal length. A 6-inch lens is not recommended because parallax limits the usable image at large to medium photo scales.

Kodak[4] Ektachrome EF Aerographic SO-397 is the recommended aerial film. SO-397 is a positive-transparency, true-color, medium-speed, fine-grain film. Film speed is ASA 160. The film must be filtered with an HF3 antivig-

[4]Mention of trade names is for convenience only and does not imply endorsement by USDA Forest Service.

netting filter. This film is the best choice because of its high resolution and sensitivity to reds and browns. Record all critical photo mission information on the aerial photography record sheet (app. I, form 2).

Photointerpretation — Photointerpretation is a critical part of the project and must be done by well-trained and experienced personnel. (If experienced photointerpreters are not available, personnel will have to be trained according to suitable photointerpretation guidelines, e.g., Wear and others 1966, Dillman and White 1982.) Photointerpretation begins with selection of appropriate stereo triplets from the roll of film provided by the aerial photographer. Triplets should be numbered consecutively and followed by A, B, or C to identify each triplet frame. The flight record sheet provided by the aerial photographer will aid in locating each photo plot center. Number each photo plot center on the master map with a triplet identifier. Any triplet sets not meeting photo mission specifications should be discarded.

Each frame of photography selected for photo interpretation requires photo scale determination. Photo scale will not be a consistent 1:6,000 in mountainous terrain. Scale differences may occur between frames and on different portions of the same frame. If the latter should occur, the photo scale should be averaged for the effective photo area.

Photo scales can be determined in several ways, depending on the information available (Reeves 1975). Both photo scale and map scale need to be recorded as a representative fraction $\frac{1}{6000}$, or as a ratio 1:6,000. Basic scale equations are as follows:

$$S = \frac{f}{H-h} \text{ or } \frac{PD}{GD} \text{ or } \frac{PD}{MD} \times MS$$

Where:

S = Photo scale
f = Focal length of camera lens, in feet
H = Flying height of aircraft above mean sea level
h = Ground elevation above mean sea level
PD = Photo distance
GD = Ground distance
MD = Map distance
MS = Map scale

An average scale is needed for the effective photo area and is expressed as:

$$S_{avg} = \frac{f}{H - h_{avg}}$$

Where: h_{avg} is an average terrain elevation.

All measurements must be expressed in the same units. Sample solutions, using the different equations, are shown in appendix III. Record the photo scale on the film triplet for use in selecting the appropriate photointerpretation sampling grids.

Photointerpretation sampling grids, constructed of clear mylar and subdivided into 36 2½-acre subplots should be used for counting ponderosa pine mortality. The same grids can be used for lodgepole pine, but only the internal 16 2½-acre subplots should be utilized for lodgepole tree counts. The appropriate sampling grid should be selected according to the photo scale determined earlier. Mylar grids, for photo scales ranging from 1:3,960 to 1:7,920, are available in each Regional office or from the Methods Application Group in Fort Collins, Colorado.

The appropriate scaled sampling grid should be taped onto the non-emulsion side of one of the outside triplicate photo frames. Check the effective area to be certain all subplots are in stereo. Permanently mark the grid placement for repositioning later.

Count all faders on each subplot in stereo and record totals (app. I, form 3).

Selection of Secondary Sampling Units— In order to randomly select 2½-acre subplots (secondary sampling units) for acquisition of ground truth data, primary and secondary sampling units must be chosen using the probability proportional to size (PPS) method (Langley 1968). Field checking 15 to 20 photo plots (PSU) with 2 subplots (SSU) per photo plot should result in a relative standard error of 20 percent. The standard error, however, is greatly influenced by variation in levels of tree mortality between photo plots and by the consistency between photointerpreter (P.I.) counts and field counts. With experienced P.I. personnel, the number of required subplots can be reduced to 1 per photo

plot or 15 for ponderosa pine and 20 for lodgepole pine. The project manager must determine the exact number of photo plots to be ground checked according to the relative standard error desired, the experience of the P.I. personnel, and the resources available (Sharpnack and Wong 1982).

In order to follow the probability proportional to size (PPS) method, first obtain the sum of the tree counts for individual photo plots (PSU) from form 3 (app. I). Enter this total and all photo plot identifications on the photo plot selection worksheet (app. I, form 4). Make accumulated counts for all photo plots.

Determine the PPS sampling interval by dividing the total tree count by the number of photo plots to be ground checked. Pick a random number (using a random number table) between one and the determined sampling interval. Start at the top of column 3 of form 4 (app. I), and select the first photo plot with an accumulated count equal to or exceeding the random number. Add the sampling interval to the random number, and repeat the selection procedure, selecting the next photo plot with an accumulated count equal to or exceeding the new number. Continue adding the sampling interval every time a photo plot is selected. Since plots are chosen with replacement, plots with high tree counts may sometimes be chosen more than once. Consider each selection as an individual area for subplot study.

Subplots are chosen in the same manner, using information on the phot subplot selection worksheet (app. I, form 5). Divide the total tree count by two to determine the sampling interval. Chose a random number between one and the sampling interval. Start at the top of the accumulative count columns, and select the first plot with an accumulative sum equal to or exceeding the random number. Add the sampling interval to the random number, and repeat the procedure to select the second subplot for field checking. Subplots may also be chosen more than once, but field data need only be collected one time.

Ground Data Acquisition — Before going to the field, stereo triplets should be prepared for field use. Cut selected triplets and attach appropriately scaled sampling grids to the non-emulsion side of the photo using the permanent grid placement marks made earlier. Next, place a small piece of masking tape on the selected subplots to be ground checked. On the emulsion side, scribe the subplot boundaries using a straight edge and etching pen. Remove the sampling grid, and highlight the subplots with an ink pen. Write subplot identification on the triplet.

Randomly selected photo subplots need to be located on the ground. All faders (>5 inches DBH) must be recorded, along with other necessary data, on form 6 (app. I). Master maps, stereo triplets, and hand-held stereo viewers will be useful in locating subplots on the ground (Klein and Lory 1981). Locate plot corners, and delineate boundaries with string or flagging. If faders are numerous within a plot, subdivide it into one-chain-wide strips to facilitate examination. Heights of three faders in each DBH class should be obtained for future volume estimates.

Data Analysis and Reporting — Form 7 and columns 1-11 of form 8 (app. I) are provided for data compilation. All data entries should be rechecked so that errors are not carried over into data analysis. Such errors are difficult to detect when reviewing the final data analysis products.

Follow the steps presented in columns 12-22 of form 8 (app. I) to facilitate data analysis. The mathematical operations heading the columns of this form indicate the column numbers to be utilized in the operation, e.g., (3)/(5) instructs that the data in column 3 should be divided by the data in column 5 for each line. Upon completion of form 8, data can be expanded and sampling errors can be obtained by following the steps of form 9 (app. I). In addition, appendix IV works through a hypothetical problem and demonstrates the related data analyses.

For reporting purposes, survey information should be presented in two distinct formats: A state map outlining county boundaries and showing mountain pine beetle losses should be submitted along with a tabular data report. Losses should be displayed separately by host type.

The tabular reporting format is critical. Information must be compared and aggregated nationally. The Forest Service Manual (FSM 12/79 AMEND G), Section 3434 -"Loss Assessment Evaluation," presents a brief explanation of reporting needs and format.

RESULTS

This survey provides tree mortality and volume loss for states by host. Any partitioning of data by ownership is based on subjective procedures, e.g., number of acres of each ownership within the area. Partitioned tree and volume losses do not carry sampling error factors. Only the state total by host, for which the survey was designed, have corresponding standard errors. Table 1 shows the FIDIS summary of mountain pine beetle infestations in ponderosa pine in the western United States for 1981 (U.S. Dept. Agric. 1981).

REFERENCES

Bennett, D.D. and W.E. Bousfield. 1979. A pilot survey to measure annual mortality caused by the mountain pine beetle in lodgepole pine on the Beaverhead and Gallatin National Forests, Montana 1978. USDA Forest Service, Northern Region, State and Private Forestry. Rpt. 79-20. Missoula, MT. 13 pp.

Ciesla, W.M. and F.M. Yasinski. 1978. Forest insect and disease information system (FIDIS) implementation plan. USDA Forest Service, Insect and Disease Management, Methods Application Group, Davis, CA.

Cochran, W.G. 1977. Sampling Techniques. 3rd ed. John Wiley & Sons, New York, NY. 429 pp.

Dillman, R.D. and W.B. White. 1982. Photointerpretation guide for identifying pines killed by the mountain pine beetle. USDA Forest Service, Forest Pest Management, Methods Application Group, Fort Collins, CO.

Hostetler, B.B. and R.W. Young. 1979. Estimation procedures for determining annual tree mortality caused by the mountain pine beetle, 1978. USDA Forest Service, Rocky Mountain Region, Tech. Rpt. R-2-20. Denver, CO. 25 pp.

Klein, W.H., D.D. Bennett and R.W. Young. 1979. A pilot survey to measure annual mortality of lodgepole pine caused by mountain pine beetle. USDA Forest Service, Forest Insect and Disease Management, Methods Application Group, Rpt. 78-4. Davis, CA. 15 pp.

Klein, W.H. and F. Lory. 1981. Field stereo viewers for aerial photography. J. For. 79(7):1-3. Davis, CA. 3 pp.

Klein, W.H., S. Tunnock, J.G.D. Ward, and J.A.E. Knopf. 1983. Aerial sketchmapping. Forest Insect and Disease Survey Methods Manual, Chapter 1.1.1. USDA Forest Service, Forest Pest Management, Methods Application Group, Fort Collins, CO. 15 pp.

Langley, P.G. 1968. The benefits of multistage variable probability sampling using space and aircraft imagery. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA. (Unpublished report).

Reeves, R.G., ed. 1975. Manual of remote sensing, vol. II. American Society of Photogrammetry. Falls Church, VA. p. 912-914.

Sharpnack, N.X. and J. Wong. 1982. Sampling designs and allocations yielding minimum cost estimators for mountain pine beetle loss assessment surveys. USDA Forest Service, Forest Pest Management, Methods Application Group, Fort Collins, CO. Rpt. No. 83-3.

U.S. Department of Agriculture, Forest Service. 1970. Evaluating southern pine beetle infestations. USDA Forest Service, State and Private Forestry, Southeastern Area, Division of Pest Control. Atlanta, GA. 34 pp.

U.S. Department of Agriculture, Forest Service. 1981. Status of mountain pine beetle infestations in ponderosa pine in the western United States. USDA Forest Service, Forest Pest Management, Methods Application Group, Fort Collins, CO. (Unpublished report).

Wear, J.F., R.B. Pope and P.W. Orr. 1966. Aerial photographic techniques for estimating damage by insects in western forests. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. Berkeley, CA.

APPENDIX I
DATA SUMMARY AND ANALYSIS FORMS

FORM 1.

POLYGON LISTING SHEET

STATE _____ TREE SPECIES _____ YEAR _____

Polygon Number	Trees per Polygon	Acres per Polygon	Trees per Acre	Polygon Number	Trees per Polygon	Acres per Polygon	Trees per Acre

FORM 2.

AERIAL PHOTOGRAPHY RECORD SHEET

Film File No._____

STATE _____ TREE SPECIES _____ YEAR _____

Mission Subject _____ Date _____

Film Type_____ Roll No._____ Location_____

Film Emulsion No. _____

Camera _____ Focal Length _____

Magazine No. _____ Photographer _____

Approx. Scale	Line or Plot No.	Dir. of Flight	Frame No.	Time of Day	Filter	Exp. Reading	f. Stop	Shutter Speed	Int. (%)	Alt.	Temp °C

Remarks: _____

_____

_____

Page _____ of _____

FORM 3.

PHOTO INTERPRETATION WORKSHEET

STATE _____ TREE SPECIES _____ YEAR _____

Photo Plot ID _____

Use grids below to record individual subplot tree counts.

90-acre grid for ponderosa pine

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Total tree count _____

Total tree count _____

40-acre grid for lodgepole pine

8	9	10	11
17	16	15	14
20	21	22	23
29	28	27	26

FORM 4.

PHOTO PLOT SELECTION WORKSHEET

STATE _____ TREE SPECIES _____ YEAR _____

Photo Plot ID	Total P.I. Count	Accumulated P.I. Count	Selected Sample
(1)	(2)	(3)	(4)

Interval _____ Random Number _____

FORM 5.

PHOTO SUBPLOT SELECTION WORKSHEET

STATE _____ TREE SPECIES _____ YEAR _____

Photo Plot ID _____

Subplot Ident.	P.I. Count	ACCUMULATED P.I. COUNT
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		

Subplot Indent.	P.I. Count	ACCUMULATED P.I. COUNT
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
31		
32		
33		
34		
35		
36		

TOTAL COUNT_____INTERVAL_____RANDOM NUMBER_____

FORM 6.

GROUND SURVEY DATA SHEET

STATE _____ TREE SPECIES _____ YEAR _____

Ownership _____ County _____ Observers _____ Date _____

Photo Plot ID _____ Ground Sample No. _____ Subplot No. _____

Diameter Breast Height	Tree Count			Tree Height		
	Trees	Total	Volume	1	2	3
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
Subplot Totals						

Note: 1. Tree count should be done using a dot tally system.
2. Express tree height in feet.
3. Obtain cubic foot volumes from local volume tables.

FORM 7.

SAMPLING PARAMETERS

STATE _____ TREE SPECIES _____ YEAR _____

(1) Acres of outbreak (total from form 1) A _____

(2) Photo Sample size (90-acre or 40-acre) a _____

(3) Total number of photo plots m _____

(4) Number of ground samples n _____

(5) Accumulated photo interpretation count
(Total from all photo plot selection worksheets, form 5.) PC _____

FORM 8.

DATA ANALYSIS WORKSHEET

STATE _____ TREE SPECIES _____ YEAR _____

Photo Plot Number	Photo Triplet ID (A,B,C)	Total Photo Plot P.I. Count	Subplot 1		Subplot 2		Subplot 1 Grand Total		Subplot 2 Grand Total	
			Ident. (1-36)	P.I. Count	Ident. (1-36)	P.I. Count	Trees	Vol. $Ft.^3$	Trees	Vol. $Ft.^3$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)

FORM 8. (continued)

Subplot Expansions		Tree Expansions		Plot Estimate for Trees	Volume Expansions Ft.^{3}		Plot Estimate for Volume	Photo Plot Expansions	Total Trees ($\hat{Y}$ Trees)	Total Volume ($\hat{Y}$ Vol.)
Sub 1 (3)/(5)	Sub 2 (3)/(7)	Sub 1 (8)x(12)	Sub 2 (10)x(13)	[(14) + (15)]/2	Sub 1 (9)x(12)	Sub2 (11)x(13)	[(17) + (18)]/2	(PC)[1]/(3)	(16)x(20)	(19)x(20)
(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)

[1]PC = Accumulated Photo Interpretation count from line (5), form 7.

FORM 9.

EXPANSION AND SAMPLING ERROR CALCULATIONS

STATE _____ TREE SPECIES _____ YEAR _____

Sum of expanded trees (add column 21, form 8) $\Sigma\hat{Y}$ Tree _____

Sum of squares (trees) $\Sigma\hat{Y}^2$ Tree _____

Sum of expanded volume (add column 22, form 8) $\Sigma\hat{Y}$ Vol _____

Sum of squares (volume) $\Sigma\hat{Y}^2$ Vol _____

Tree Estimates

$$\text{Y Tree} = \frac{A}{(a)(m)} \cdot \frac{\Sigma\hat{Y}\ \text{Tree}}{n}$$

_____

Standard error trees (S.E. Tree)

$$\text{S.E. Tree} = \sqrt{\left[\frac{A}{(a)(m)}\right]^2 \left[\frac{\Sigma\hat{Y}^2\ \text{Tree} - \frac{(\Sigma\hat{Y}\ \text{Tree})^2}{n}}{n(n-1)}\right]}$$

_____

Relative standard error trees (R.S.E. Tree)

$$\text{R.S.E. Tree} = \frac{\text{S.E. Tree}}{\text{Y Tree}} \cdot 100$$

_____

Volume Estimates

$$\text{Y Vol} = \frac{A}{(a)(m)} \cdot \frac{\Sigma\hat{Y}\ \text{Vol}}{n}$$

_____

Standard Error volume (S.E. Vol)

$$\text{S.E. Vol} = \sqrt{\left[\frac{A}{(a)(m)}\right]^2 \left[\frac{\Sigma\hat{Y}^2\ \text{Vol} - \frac{(\Sigma\hat{Y}\ \text{Vol})^2}{n}}{n(n-1)}\right]}$$

_____

Relative standard error volume (R.S.E. Vol)

$$\text{R.S.E. Vol} = \frac{\text{S.E. Vol}}{\text{Y Vol}} \cdot 100$$

_____

APPENDIX II

COMPUTER PROGRAM IN BASIC TO GENERATE AN EQUAL INTERVAL GRID

```
100 INTEGER SPACE,LINE
120 DIM A$(25),B$(3)
140 INPUT "WHAT AREA IS THE GRID FOR?     ":A$(25)
160 INPUT "AREA IN ACRES                  ": AREA
180 INPUT "NUMBER OF PHOTOS               ": NP
200 INPUT "MAP SCALE                      ": MS
220 IF MS > 4.0 THEN 980
240 INPUT "NUMBER OF LINES                ": LINES
260 INPUT "IS EVERYTHING OK?  YES OR NO? ":B$(3)
280 IF B$(3)="NO" THEN 140
300 FOR L=1 TO 5
320 PRINT
340 NEXT L
360 PRINT TAB(50);"PHOTO      POINTS      GRID"
380 PRINT
400 PRINT TAB(10);A$(25)
420 PRINT
440 PRINT TAB(10);"AREA IN ACRES"; AREA
460 PRINT
480 PRINT TAB(10);"NUMBER OF PHOTOS"; NP
500 PRINT
520 PRINT TAB(10);"MAP SCALE"; MS
540 FOR M=1 TO 5
560 PRINT
580 NEXT M
600 LET AREA2=AREA/640
620 LET INT1=SQR(AREA2/NP)
640 LET INT2=INT1*MS
660 SPACE=INT2*10
680 LINE=INT2*6
700 PRINT TAB(50);"NORTH          NORTH          NORTH"
720 PRINT
740 PRINT
760 FOR N=1 TO LINES
780 FOR J=1 TO 120 STEP SPACE
800 PRINT TAB(J)"+";
820 NEXT J
840 FOR K=1 TO LINE
860 PRINT
880 NEXT K
900 NEXT N
920 PRINT
940 PRINT TAB(50);"SOUTH          SOUTH          SOUTH"
960 STOP
980 PRINT "YOUR MAP SCALE IS TOO BIG!"
1000 GO TO 200
1020 STOP
1040 END
```

APPENDIX III

SAMPLE SOLUTIONS FOR SCALE DETERMINATION

Selection of the equation to be used should be based on the data available. Photography over terrain void of good landmarks may create problems in acquiring measurements on photos and maps.

Example 1. Aerial photos are taken over mountainous terrain with an 8¼ inch (.6875 ft.) focal-length camera at an altitude of 10,000 feet above sea level. Ground elevation varies within the photo from 7,000 feet (highest terrain) to 5,000 feet (lowest terrain).

Solution: $S_{avg} = \frac{f}{H - h_{avg}}$

$$S_{avg} = \frac{.6875 \text{ ft.}}{10{,}000 \text{ ft} - 6{,}000 \text{ ft}} = \frac{.6875^*}{4{,}000} = \frac{1}{5818} \text{ or } 1{:}5818$$

*(divide numerator and denominator by .6875)

Example 2. Ground measurements were acquired in a plot area. Distance between two points along a road measure 2,720 feet. The same two points are located on the photo and measure 5.40 inches (.450 feet).

$$\text{Solution: } S = \frac{PD}{GD} = \frac{.450 \text{ ft}}{2{,}720 \text{ ft}} = \frac{1}{6044} = \text{ or } 1{:}6044$$

Example 3. Good landmarks appear on the aerial photo as well as USGS 7½ minute quad map (map scale 1:24,000). Two small lakes measure 6.85 inches apart on the photo and 1.85 inches on the map.

$$\text{Solution: } S = \frac{PD}{MD} \times MS$$

$$= \frac{6.85}{1.85} \times \frac{1}{24{,}000}$$

$$= 3.7 \times \frac{1}{24{,}000} = \frac{1}{24{,}000/3.7}$$

$$= \frac{1}{6486} \text{ or } 1{:}6486$$

APPENDIX IV

HYPOTHETICAL PROBLEMS

The following hypothetical problem is intended to serve as an example of the data analyses necessary for this survey method.

A survey of tree mortality is made over 100,000 acres of ponderosa pine infested by mountain pine beetle in Colorado. Fifty 90-acre photo plots are established in a single stratum within the outbreak area. Two subplots are ground checked on each of 10 photo plots for which a total of 2,000 faders are recorded by photointerpreters.

Sampling parameter information is entered on form 7 in the following manner.

FORM 7.

SAMPLING PARAMETERS

STATE Colorado TREE SPECIES Ponderosa Pine YEAR 83

(1)	Acres of outbreak (total from form 1)	A	100,000
(2)	Photo Sample size (90-acre or 40-acre)	a	90
(3)	Total number of photo plots	m	50
(4)	Number of ground samples	n	10
(5)	Accumulated photo interpretation count (Total from all photo plot selection worksheets, form 5.)	PC	2,000

Photo interpretation and ground data from forms 5 and 6 are entered on the data analysis worksheets (form 8) and exposures are computed as follows:

FORM 8.

DATA ANALYSIS WORKSHEET

STATE Colorado TREE SPECIES Ponderosa Pine YEAR 83

Photo Plot Number	Photo Triplet ID (A,B,C)	Total Photo Plot P.I. Count	Subplot 1		Subplot 2		Subplot 1 Grand Total		Subplot 2 Grand Total	
			Ident. (1-36)	P.I. Count	Ident. (1-36)	P.I. Count	Trees	Vol. Ft.^{3}	Trees	Vol. Ft.^{3}
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
5	B	100		5		20	6	90	21	315
15	B	20		1		1	1	15	1	15
18	B	250		30		50	32	480	53	795
25	B	30		1		2	1	15	2	30
27	B	300		20		15	21	315	16	240
30	B	750		100		75	105	1575	80	1200
33	B	100		5		5	5	75	5	75
37	B	250		20		6	18	270	7	105
42	B	100		25		15	28	420	20	300
46	B	100		10		15	11	165	14	210

FORM 8. (continued)

Subplot Expansions		Tree Expansions		Plot Estimate for Trees	Volume Expansions Ft.^{3}		Plot Estimate for Volume	Photo Plot Expansions	Total Trees ($\hat{Y}$ Trees)	Total Volume ($\hat{Y}$ Vol.)
Sub 1 (3)/(5)	Sub 2 (3)/(7)	Sub 1 (8)x(12)	Sub 2 (10)x(13)	[(14) + (15)]/2	Sub 1 (9)x(12)	Sub2 (11)x(13)	[(17) + (18)]/2	(PC)[1]/(3)	(16)x(20)	(19)x(20)
(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
20	5	120	105	112.5	1800	1575	1687.5	20	2250	33750
20	20	20	20	20	300	300	300	100	2000	30000
8.3	5	265.6	265	265.3	3984	3975	3979.5	8	2122.4	31836
30	15	30	30	30	450	450	450	66.67	2000.1	30001.5
15	20	315	320	317.5	4725	4800	4762.5	667	2117.73	31765.8
7.5	10	787.5	800	793.75	11812.5	12,000	11906.25	2.67	2119.31	31789.6
20	20	100	100	100	1500	1500	1500	20	2000	30000
12.5	41.6	225	291.2	258.1	3375	4368	3871.5	8	2064.8	30972
4	6.67	112	133.4	122.7	1680	2001	1840.5	20	2454	36810
10		110	93.4	101.7	1650	1400.7	1525.35	20	2034	30507

[1]PC = (Accumulated Photo Interpretation count) from line (5), form 7.

Numbers of trees, volume, and their respective sampling errors are computed on form 9, as follows:

FORM 9.

EXPANSION AND SAMPLING ERROR CALCULATIONS

STATE Colorado TREE SPECIES Ponderosa Pine YEAR 83

Sum of expanded trees (add column 21, form 8) $\Sigma \hat{Y}$ Tree 21162.34

Sum of squares (trees) $\Sigma \hat{Y}^2$ Tree 44,966,408

Sum of expanded volume (add column 22, form 8) $\Sigma \hat{Y}$ Vol 317431.9

Sum of squares (volume) $\Sigma \hat{Y}^2$ Vol 10,117,246,050

Tree Estimates

$$\text{Y Tree} = \frac{A}{(a)(m)} \cdot \frac{\Sigma \hat{Y} \text{ Tree}}{n}$$

$$= \frac{10{,}000}{(90)(50)} \cdot \frac{21162.34}{10} = 46980.39$$

46980.39

Standard error trees (S.E. Tree)

$$\text{S.E. Tree} = \sqrt{\left[\frac{A}{(a)(m)}\right]^2 \left[\frac{\Sigma \hat{Y}^2 \text{ Tree} - \frac{(\Sigma \hat{Y} \text{ Tree})^2}{n}}{n(n-1)}\right]}$$

$$= \sqrt{\left[\frac{100000}{(90)(50)}\right]^2 \left[\frac{44966408 - \frac{447844634}{10}}{10(9)}\right]}$$

$$= 999.1$$

999.1

Relative standard error trees (R.S.E. Tree)

$$\text{R.S.E. Tree} = \frac{\text{S.E. Tree}}{\text{Y Tree}} \cdot 100$$

$$= \frac{999.1}{46980.39} \cdot 100$$

$$= 2.13\%*$$

2.13%*

Volume Estimates

$$\text{Y Vol} = \frac{A}{(a)(m)} \cdot \frac{\Sigma \hat{Y}\ \text{Vol}}{n}$$

704,699

$$= \frac{100000}{(90)(50)} \cdot \frac{317431.9}{10}$$

$$= 704699$$

Standard Error volume (S.E. Vol)

$$\text{S.E. Vol} = \sqrt{\left[\frac{A}{(a)(m)}\right]^2 \left[\frac{\Sigma \hat{Y}^2\ \text{Vol} - \frac{(\Sigma \hat{Y}\ \text{Vol})^2}{n}}{n(n-1)}\right]}$$

14988.39

$$= \sqrt{\left[\frac{100000}{(90)(50)}\right]^2 \left[\frac{10117146050 - \frac{100763011100}{10}}{10(9)}\right]}$$

$$= 14988.39$$

Relative standard error volume (R.S.E. Vol)

$$\text{R.S.E. Vol} = \frac{\text{S.E. Vol}}{\text{Y Vol}} \cdot 100$$

2.13%*

$$= \frac{14988.39}{704699} \cdot 100$$

$$= 2.13\%*$$

*In this hypothetical example all trees were assigned a volume of 15 ft³/tree to simplify computations. Since there was no variation in tree volume, relative S.E. of trees and volume is identical. This will *not* occur with actual field data.

FIGURE 1.
A GRAPHIC DISPLAY OF THE SURVEY DESIGN.

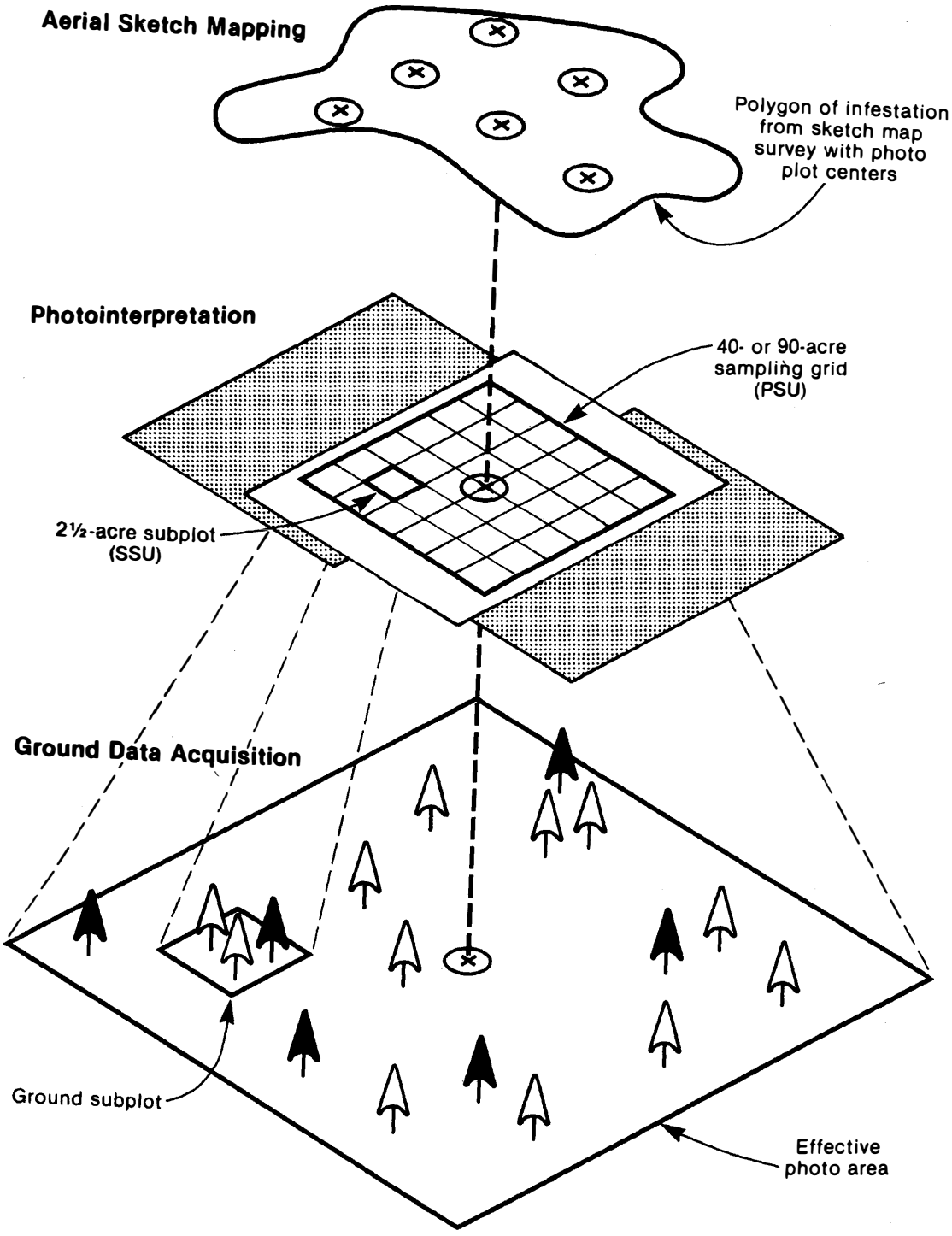
Aerial Sketch Mapping
Polygon of infestation from sketch map survey with photo plot centers
Photointerpretation
40- or 90-acre sampling grid (PSU)
2½-acre subplot (SSU)
Ground Data Acquisition
Ground subplot
Effective photo area

TABLE 1.

STATUS OF MOUNTAIN PINE BEETLE INFESTATIONS IN PONDEROSA PINE IN THE WESTERN UNITED STATES — 1981

State	Land Ownership Class	Thousands of Acres Infested	Thousands of Trees Killed	Volume[1] Killed (MCF)
Colorado	National Forest	61.7	38.4	574.8
	Other Federal	0.5	0.4	7.4
	State & Private	19.7	15.6	232.4
	TOTAL	81.9	54.4	814.6
Montana	National Forest	18.9	8.1	53.6
	Other Federal	6.4	2.7	18.2
	State & Private	51.4	21.7	145.1
	TOTAL	76.4	32.5 ± 8.6%[2]	216.9 ± 9.0%[2]
Oregon	National Forest	43.1	50.7	707.9
	Other Federal	0.7	0.8	11.1
	State & Private	23.8	27.6	387.1
	TOTAL	67.6	79.1 ± 16.6%	1106.1 ± 35.5%
S. Dakota	National Forest	177.3	280.4	4766.8
	Other Federal	13.8	21.8	370.6
	State & Private	38.9	61.4	1043.8
	TOTAL	230.0	363.6	6181.2
Utah	National Forest	7.8	164.1	5133.3
	Other Federal	0.1	1.8	54.6
	State & Private	0.4	8.7	273.0
	TOTAL	8.3	174.6 ± 4.0%	5460.9 ± 7.0%
Washington	National Forest	5.3	4.9	87.7
	Other Federal	3.2	2.9	50.1
	State & Private	17.4	16.1	279.6
	TOTAL	25.9	23.9 ± 20.2%	417.4 ± 46.7%
Wyoming[3]	National Forest	9.1	134.9	2310.3
	Other Federal	0.0	0.0	0.0
	State & Private	9.4	42.5	722.5
	TOTAL	18.5	178.4	3032.8

[1]Does not include National Parks, Monuments, Wilderness or other dedicated areas.

[2]% Relative Standard Error — These estimates do not include infested trees removed as a result of suppression projects, salvage operations or firewood gathering.

[3]Estimates made from aerial sketch map surveys.